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TO: MR. J.E. MITCHELL
Manager, Technical Services & Development
Program Support & Services Division
C25F6

EVALUATION OF THE LOAD SHIFTING CAPABILITIES OF THREE-ELEMENT ELECTRIC WATER HEATERS

C.A. McGugan

ABSTRACT

Two three-element electric water heaters were tested for delivery and load shifting capabilities. The tanks were able to meet the CSA Standard C191 draw schedule requirements. The three-element tanks are not effective in shifting of water heating electrical load from the 16 hour daytime period to the 8 hour night period. They will, however provide effective reduction of shorter term peaks, on the order of 1 or 2 hours. Further research on this type of water heater should concentrate on the short term load management capabilities, and reduction of standby loss potential.

INTRODUCTION

The three-element tanks are 270 L electric storage water heaters with an extra element placed about halfway up the tank. The main advantage of this design in comparison with standard electric water heaters is some capability of load shifting for demand management purposes.

Two of these three-element tanks were tested under various draw profiles to determine how they might help to reduce electric demand during the peak hours of 7:00 am to 11:00 pm.

TANK DESIGN

The tanks are standard 270 L electric water heaters with an extra element installed at about the centre of the tank. Figure 1 shows a diagram of the tank. The controls are modified so that there is one circuit for the top element which is controlled by the upper thermostat, and a second circuit for the bottom two elements. The top thermostat is a double acting relay which energizes

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either the top element or the bottom circuit, depending on the temperature of the water. The two bottom elements have separate thermostats so that one or both of them can operate when the bottom circuit is energized.

The top element is a standard 3800 W element while the bottom elements have been selected to give a maximum demand of 3800 W. This requires that the sum of the wattages of the two bottom elements be no higher than 3800 W, since both of them can operate at the same time.

With a typical two-element tank (ie, 3800 W top and bottom), any reasonably sized hot water draw will cause the lower element to come on, and stay on until the tank is up to the set temperature. For a very large draw, the top element will be energized for a period of time and then power will be switched over to the bottom element. In either case the tank will operate at a maximum power input of 3800 W.

With the three-element tank (ie, 3800/3000/600 or 800 W), a small draw (about 15 L) will cause the bottom element to come on, just as it would in a two-element tank; however, the power requirement will be much lower (600 or 800 W), depending on which element is used. The middle element will not come on unless there is a relatively large draw (about 120 L), or a series of smaller draws in rapid succession. The recovery rate for the 800 W element is about 12 L/h, compared to about 60 L/h for a 3800 W element and therefore, the demand profile for the three-element tank should be much different than that of a standard two-element tank.

As an example, assuming a morning draw of about 100 L, the standard tank element would operate for about 100 minutes, at 3800 W, while the three-element tank should take about 8 hours, at 800 W, to fully recover, provided there were no other draws. If the peak draw occurs in the evening, some of the water heating electrical requirements could be shifted to off-peak hours with the three-element tank.

TEST METHODS AND INSTRUMENTATION

The two water heaters were installed in the OHRD water heater testing facility. The following tests described in the CSA Standard C191, Series M1983/1/, were performed to establish their thermal performance and delivery capability:

1.	Tank Capacity	Clause	5.4
2.	Energy Efficiency		5.6
3.	Heating Element Input		5.5
4.	Delivery		5.11

Additional delivery tests were carried out using draw schedules more typical of average family use (e.g. ASHRAE)/2,3/. Table 1 provides details of the draw schedules used.

Modifications to the water heater were carried out where the results suggested that improved operation could be achieved.

In addition, draw tests were carried out on a standard two-element 270 L tank in order to provide data for comparison to determine demand management capabilities.

TEST RESULTS AND DISCUSSION

1. The volume of each of the tanks was measured to be 270 L.

2. The initial standby loss tests showed that the heat loss from the prototype tanks was above the CSA C191 requirement for 270 L tanks. Insulation blankets were installed on the tanks to bring the energy losses to below the 115 W maximum. For both tanks, the loss was 107 W with the blankets installed.

3. The results of the heating element input tests are shown in Table 2.

4. Each tank was subjected to the standard 455 L draw schedule as described in CSA Standard C191.0. The total electrical energy use for the standard tank was 28.8 kWh over a 24-hour period, with 27.8 kWh used during the 16 hour peak period between 7:00 am and 11:00 pm. The three-element tank with the 800 W bottom element used a total of 25.1 kWh over a 24-hour period, with 25 kWh in the 16 hour peak period. The three-element tank with the 600 W bottom element used a total of 26.0 kWh over 24 hours, with 23.9 kWh used in the 16 hour peak period. The results for the various draw tests conducted on the three tanks are summarized in Table 3.

   The load shifting that can be achieved with the three-element tanks is very dependant on the draw schedule used. With very heavy draws, the middle element will be activated, and the lower element will only heat the part of the tank between the lower element and the middle element. Unless there is a relatively large draw just before 11:00 pm, very little of the demand can be shifted from the 16 hour peak period to the 8 hour off-peak period. The greatest potential benefit from the three-element tank appears to be in peak shifting within the 16 hour day-time period.

   The electrical energy use profiles over the 16 hour peak period are shown in Figures 2 to 4. The three-element tanks show lower peaks than the standard tank for the first 2 hours (starting at 8:00 am) of the CSA draw schedule. This may be beneficial where there is concern about short-term peaks. For the other two schedules, considered to better represent the actual residential hot water use pattern, the power demand of the three-element tank appears more balanced and slightly lower than for the standard tank.

   Additional draw tests were carried out with the thermostat for the middle element turned down so that it would not operate unless there was a very heavy draw. Figure 5 shows the results for these tests. With the middle thermostat turned down, the middle element did not operate as much, and more of the water heating was done with the lower element; however the tanks were not able to meet the 455 L draw schedule.

The three-element tanks may have other benefits than peak load shifting. For example, the low wattage of the bottom element means that a very low watt density element could be used without having a physically large element. This could help to extend the life of the bottom element in scaling conditions.

The use of three elements in a tank would also make it easier to control the amount of water that is heated for use each day. In a household where normal usage is relatively low, the bottom element could be disabled through the use of a manual switch, so that only the middle and upper elements are used. This would reduce the standby losses from the tank. If the usage pattern changes so that more hot water is required, then the bottom element could be re-activated. A further refinement of this would be through the use of an intelligent controller which would monitor the use patterns of the household, and only heat enough water to meet the requirements, in the most energy efficient and demand controlling way. However, special care will be required to prevent potential bacterial growth in the tank.

CONCLUSIONS AND RECOMMENDATIONS

1. The three-element tanks are capable of meeting the CSA C191 delivery requirements.

2. The three-element tanks are not effective in shifting of water heating electrical load from the 16 hour daytime period to the 8 hour night period. They will, however, provide effective reduction of shorter term peaks, on the order of 1 or 2 hours.

3. The three-element tank could be used with an adaptive controller, or manual switch to provide control of the amount of water heated for use each day. In houses with low consumption, the bottom element could be disabled, potentially reducing the standby heat loss from the tank. Special care will be needed to prevent potential bacteria growth.

4. Further research on this type of water heater should concentrate on the short-term load management capabilities, and reduction of standby loss potential.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

C.A. McGugan
Engineer
Utilization Section

Reviewed:

M. Perlman
Unit Head - Energy Management
Utilization Section

CAM:djb

REFERENCES

1. CSA C191 Series-M1983, CSA Standard on performance of Electric Storage Tank Water Heaters. Canadian Standards Association, 1983.

2. CAN/CSA-F379.1-88, Solar Domestic Hot Water Systems (Liquid to Liquid Heat Transfer). Canadian Standards Association, 1988.

3. Perlman, M., Development of Residential Hot Water Use Patterns, Ontario Hydro Research Division, December, 1984.

TABLE 1: Water Draw Schedules Used in Tests (Litres)

TIME OF DAY	CSA C191 DRAW	ASHRAE DRAW	CSA F379 DRAW
1:00			
2:00			
3:00			
4:00			
5:00			
6:00			
7:00	40.5	20	5
8:00	40.5	40	30
8:30			5
9:00	46	30	0
9:30			5
10:00	91	30	55
10:30	82		55
11:00	50	25	45
12:00	14	25	0
12:30			5
13:00	14	25	0
14:00	14	20	
15:00	4.5	20	
16:00	14	15	
17:00	9	15	5
18:00	9	25	10
19:00	13	30	45
20:00	9	30	30
21:00	4.5	25	5
22:00		25	
23:00		25	
24:00		25	
TOTAL	455	450	300

TABLE 2: Heating Element Wattages

	Top Element	Middle Element	Lower Element
Tank 1	3542	2894	807
Tank 2	3715	3067	646

TABLE 3: Results of Draw Tests - Energy Consumption (kWh)

Tank Description	Period	CSA C191 Draw	ASHRAE Draw	CSA F379.1 Draw
Standard Tank	16 Hour Peak	27.8	25.5	19.7
	8 Hour Off-Peak	1.0	3.7	0.9
	TOTAL	28.8	29.2	20.6
800 W Lower Element	16 Hour Peak	25.0	21.7	15.7
	8 Hour Off-Peak	0.1	7.7	2.0
	TOTAL	25.1	29.4	17.7
600 W Lower Element	16 Hour Peak	23.9	21.0	12.9
	8 Hour Off-Peak	2.1	7.8	3.3
	TOTAL	26.0	28.8	16.2

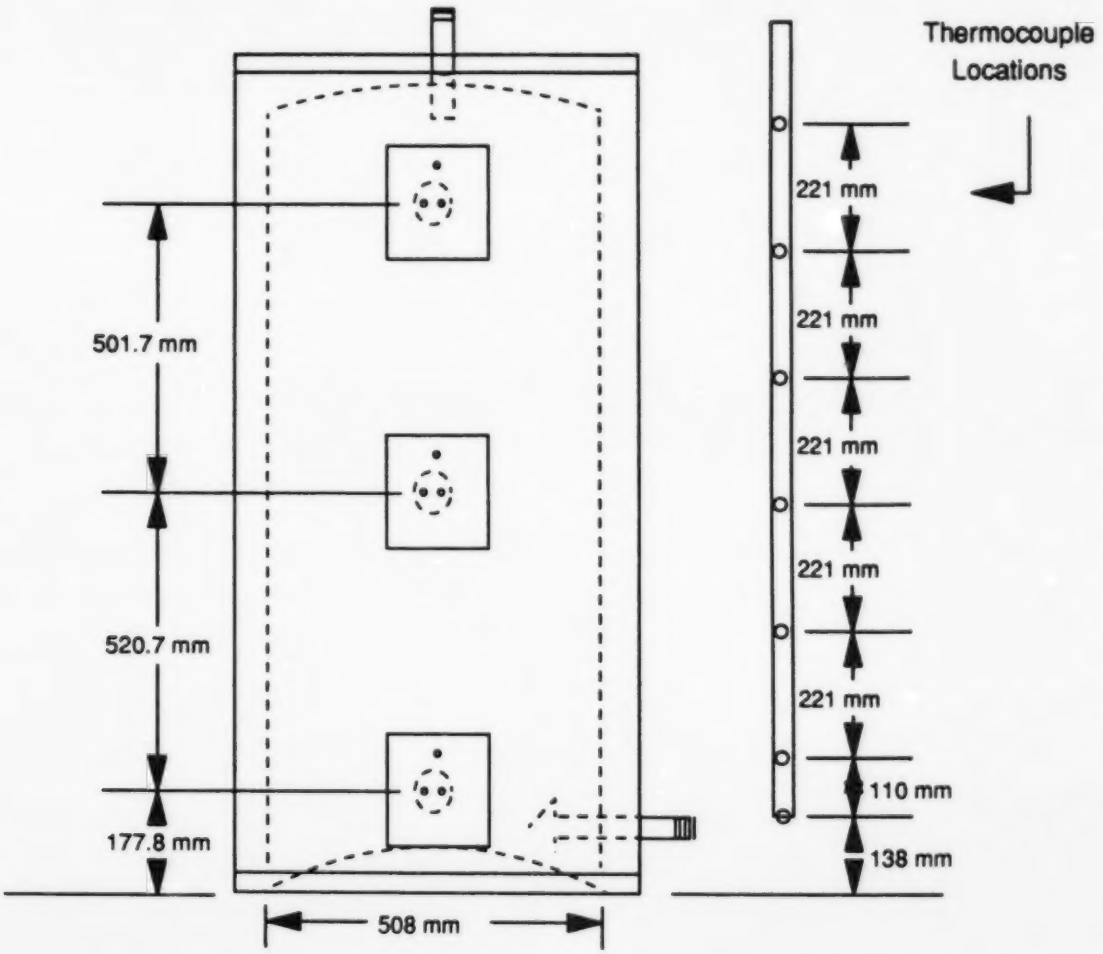

Figure 1 - Diagram of 3 Element Tank

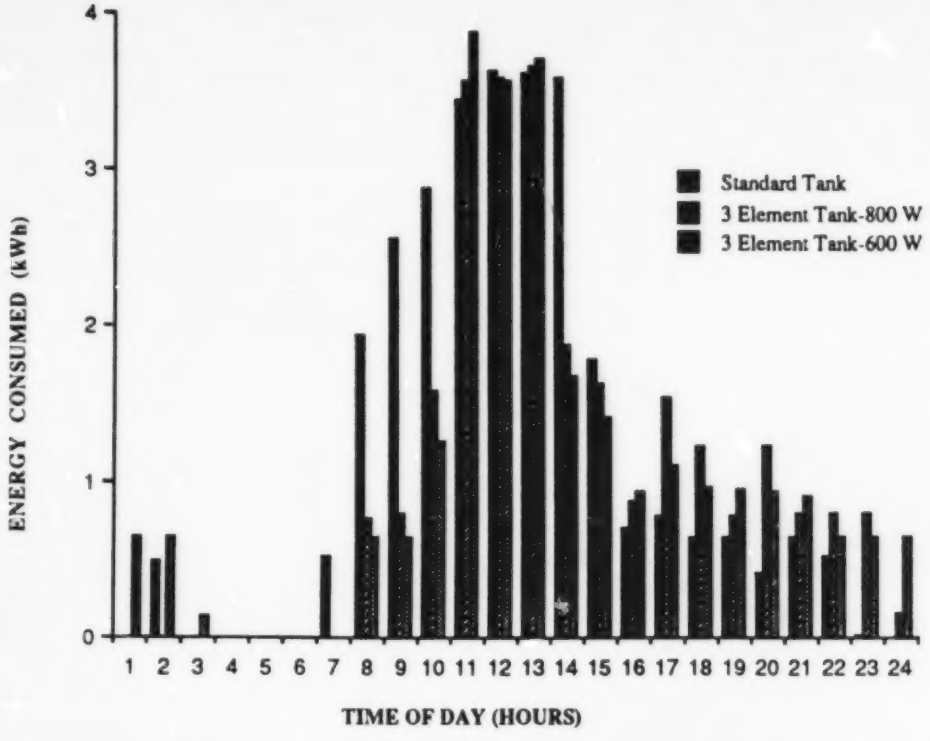
ENERGY CONSUMED (kWh)
0
1
2
3
4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME OF DAY (HOURS)
Standard Tank
3 Element Tank-800 W
3 Element Tank-600 W

FIGURE 2: TEST RESULTS FOR CSA C191 DRAW SCHEDULE

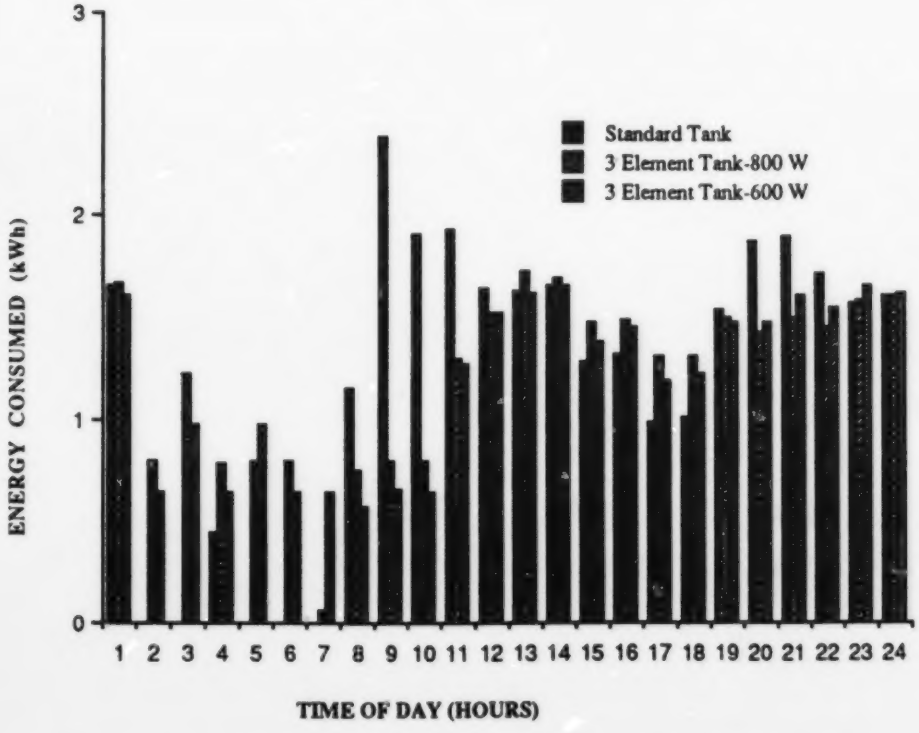
ENERGY CONSUMED (kWh)
0
1
2
3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME OF DAY (HOURS)
Standard Tank
3 Element Tank-800 W
3 Element Tank-600 W

FIGURE 3: TEST RESULTS FOR ASHRAE DRAW SCHEDULE

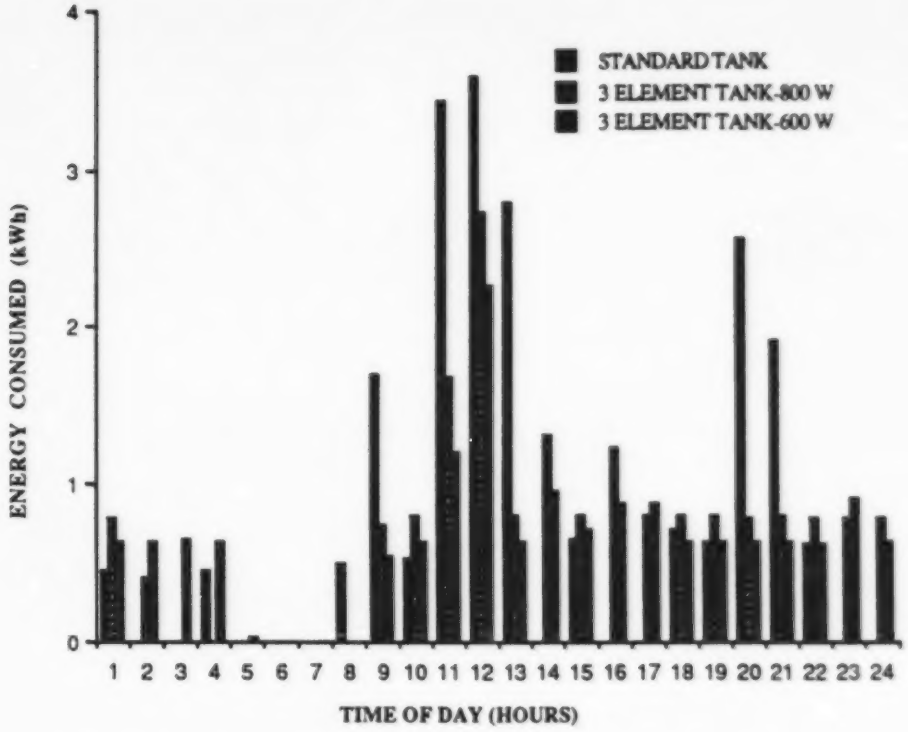
STANDARD TANK
3 ELEMENT TANK-800 W
3 ELEMENT TANK-600 W
ENERGY CONSUMED (kWh)
0
1
2
3
4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME OF DAY (HOURS)

FIGURE 4: TEST RESULTS FOR CSA F 379.1 DRAW SCHEDULE

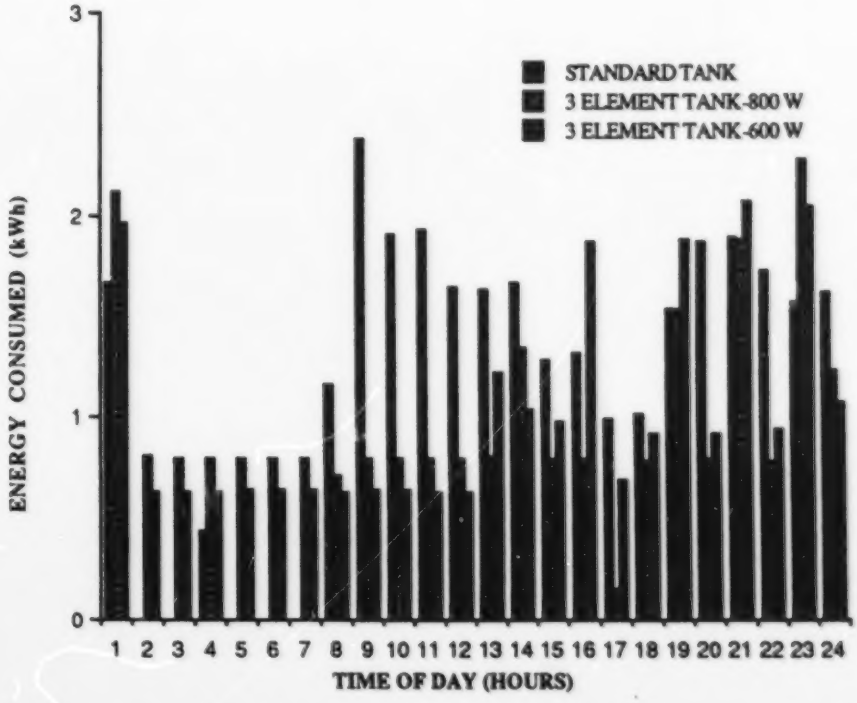
STANDARD TANK
3 ELEMENT TANK-800 W
3 ELEMENT TANK-600 W
ENERGY CONSUMED (kWh)
0
1
2
3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME OF DAY (HOURS)

FIGURE 5: TEST RESULTS FOR ASHRAE DRAW SCHEDULE WITH MIDDLE THERMOSTAT SET DOWN